Canadian Centre
for Occupational
Health and Safety

Centre canadien
d'hygiène et de
sécurité au travail

VIBRATION EXPOSURE IN THE WORKPLACE

P89 - 28E

VIBRATION EXPOSURE IN THE WORKPLACE

Bhawani Pathak

David Charron

Canadian Centre for Occupational Health and Safety

December 1989

CCOHS/CCHST

91-00471/

VIBRATION EXPOSURE IN THE WORKPLACE

This publication was prepared as a source of general information for health and safety committees and others with an interest in understanding and reducing the occupational risk of vibration exposure.

Each publication produced by CCOHS undergoes several stages of review. As a part of this review, representatives from government, employers, and labour are requested to comment on draft copies of CCOHS documents for technical accuracy and readability.

Although every effort is made to ensure accuracy and completeness of the information, it is understood that CCOHS makes no warranty as to the accuracy or completeness of such information and assumes no liability for any damages or loss suffered as a result of any inaccuracy or incompleteness therein.

In the interest of the widest possible dissemination of occupational health and safety information, CCOHS invites users to copy and distribute its publications. Appropriate written acknowledgment is requested and appreciated. CCOHS asks that users report the number of publications so distributed--please notify the Inquiries Service.

Cette publication est offerte en français sous le titre : Exposition aux vibrations en milieu de travail.

CCOHS NUMBER P89-28E
ISBN 0-660-13447-0
DSS CATALOGUE NUMBER CC273-2/89-28E

Published 1989

---

250 Main Street East
Hamilton Ontario
L8N 1H6
416-572-2981
FAX 416-572-2206

CCOHS CCHST

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	SOME BASICS OF VIBRATION	1
	Frequency	2
	Amplitude	2
	Acceleration	2
	Resonance	2
3.	TYPES OF VIBRATION EXPOSURE	2
4.	HEALTH EFFECTS OF HAND-ARM VIBRATION	4
	Stage 1	5
	Stage 2	5
	Stage 3	5
	Stage 4	5
5.	HEALTH EFFECTS OF WHOLE-BODY VIBRATION	7
6.	COMBINED EFFECT OF NOISE AND VIBRATION	7
7.	MEASURING VIBRATION	8
8.	EXPOSURE GUIDELINES	8
	Hand-Arm Vibration	8
	Whole-Body Vibration	9
9.	VIBRATION CONTROL	12
	Hand-Arm Vibration	12
	Whole-Body Vibration	13
10.	SUMMARY	13
	FURTHER READING	14

CCOHS/CCHST

1. INTRODUCTION

Many tools and machines vibrate. A worker in contact with a vibrating machine receives vibrational energy which can, after prolonged exposure, cause certain health conditions, disorders or diseases. The risk of disease depends on the characteristics of the vibration, the part of the body which receives the vibration energy and the duration (years) of exposure.

This publication summarizes the health hazards of vibration exposure and describes methods for measuring vibration and ways to control vibration exposure in the workplace.

2. SOME BASICS OF VIBRATION

Vibration is characterized by frequency, amplitude and acceleration (see Figure 1).

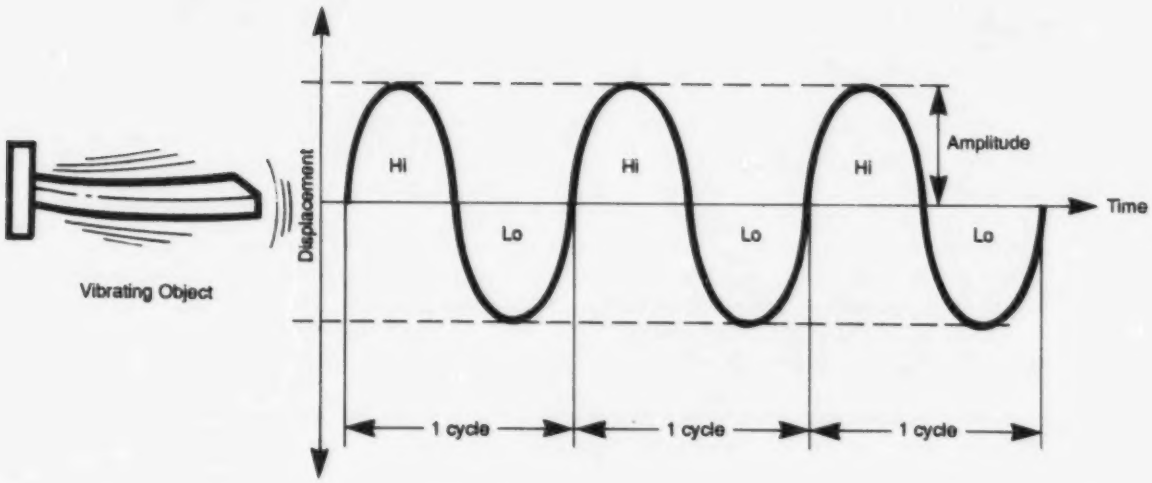

Figure 1 - Representation of vibration

Frequency

A vibrating object moves back and forth about its normal stationary position. A cycle occurs when the object moves from one extreme position to the other extreme, and back again. The number of cycles that a vibrating object completes in one second is called frequency. The unit of frequency is hertz, Hz. One hertz equals one cycle per second.

Amplitude

A vibrating object moves to a certain maximum distance on either side of its stationary position. Amplitude is the distance from the stationary position to the extreme position on either side and is measured in metres, m. The intensity of vibration depends on amplitude.

Acceleration

The speed of a vibrating object is not constant. It moves fastest as it passes through its stationary position to an extreme position. The vibrating object slows down as it approaches the extreme, where it stops and then moves in the opposite direction through the stationary position toward the other extreme. Acceleration is a measure of how quickly speed changes with time. Acceleration is expressed in units of metres per second squared, m/s^2.

Resonance

All objects tend to vibrate at one particular frequency that depends on the composition of the object, its size and shape. This frequency of natural vibration is called the resonant frequency. A vibrating machine transfers the maximum amount of energy to an object when the machine vibrates at the object's resonant frequency.

3. TYPES OF VIBRATION EXPOSURE

Contact with a vibrating machine transfers vibration energy to a person's body. Depending on how the exposure occurs, vibration may affect a major part of the worker's body or only a particular organ. The effect of vibration exposure also depends on the frequency of vibration. Each organ of the body has its own resonant frequency. If exposure occurs at or near any of these resonant frequencies the resulting effect is greatly increased.

Segmental vibration is vibration exposure that affects an organ or part of the body. The most widely studied and most common type of segmental vibration exposure affects the hands and arms. Hand-arm vibration affects workers such as operators of chain saws, chipping tools, jackhammers, jack leg drills, grinders and many other hand-held tools.

When the vibration energy enters the body through a seat or the floor, it affects the entire body or a number of organs in the body. This is called whole-body vibration. Exposed groups include operators of trucks, buses, tractors and those who work on vibrating floors.

Table 1 lists examples of vibration exposure in various industries.

Table 1 - Examples of occupational vibration exposure

Industry	Type of Vibration	Common Vibration Sources
Agriculture	Whole body	Tractors
Boiler making	Hand-arm	Pneumatic tools
Construction	Whole body Hand-arm	Heavy equipment vehicles Pneumatic drills, Jackhammers
Diamond cutting	Hand-arm	Vibrating hand tools
Forestry	Whole body Hand-arm	Tractors Chain saws
Foundries	Hand-arm	Vibrating cleavers
Furniture manufacture	Hand-arm	Pneumatic chisels
Iron and steel	Hand-arm	Vibrating hand tools
Lumber	Hand-arm	Chain saws
Machine tools	Hand-arm	Vibrating hand tools
Mining	Whole body Hand-arm	Vehicle operation Rock drills
Riveting	Hand-arm	Hand tools
Rubber	Hand-arm	Pneumatic stripping tools
Sheet metal	Hand-arm	Stamping equipment
Shipyards	Hand-arm	Pneumatic hand tools
Shoe-making	Hand-arm	Pounding machine
Stone dressing	Hand-arm	Pneumatic hand tools
Textile	Hand-arm	Sewing machines, Looms
Transportation	Whole body	Vehicles

4. HEALTH EFFECTS OF HAND-ARM VIBRATION

Vibration-induced white finger (VWF) is the most common condition among the operators of hand-held vibrating tools. Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as vibration syndrome. The symptoms and effects of VWF are aggravated when the hands are exposed to cold.

Workers exposed to hand-arm vibration commonly report:

- attacks of whitening (blanching) of one or more fingers when exposed to cold
- tingling and loss of sensation in the fingers
- loss of light touch
- pain and cold sensations between periodic white finger attacks
- loss of grip strength
- bone cysts in fingers and wrists

These symptoms are sometimes called Raynaud's Phenomenon of Occupational Origin. Table 2 grades the stages of vibration-induced white finger.

Table 2 - The scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome

Stage	Grade	Description
0		No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting finger tips and middle of the finger and rarely also the finger parts close to the palm.
3	Severe	Frequent attacks affecting most fingers
4	Very severe	Same symptoms as in stage 3 with degenerative skin changes in the finger tips

Source: Gemne, G. et al. Scandanavian Journal of Work, Environment and Health. Vol. 13, no. 4 (1987) p. 275-278.

Stage 1

In the early stages of vibration exposure, workers may occasionally experience tingling, followed by numbness of fingers. These conditions usually do not interfere with work or other activities.

Stage 2

After exposure to intense vibration, the fingers may become swollen, painful and inflexible. This can happen within a year, or after several years, depending on the intensity of exposure. At this stage, the symptoms subside if the exposure stops. But further exposure leads to whitening of fingers, especially during colder temperatures. People working in cold are prone to early morning attacks, which can last from 15 to 60 minutes.

Stage 3

Attacks can occur in both summer and winter and interfere with work. The victim loses the ability to do fine work, to pick up small objects and is unable to distinguish between hot and cold. At this stage recreational activities are affected.

Stage 4

In advanced cases, episodes of a bluish discolouration of the fingers are likely. Blood vessels lose their ability to open and close quickly. In a small number of cases, the affected worker also suffers from degeneration of the skin, especially at the fingertips.

The severity of vibration-induced white finger diseases depends on several other factors, such as the characteristics of vibration exposure, work practice, personal history and habits. Table 3 summarizes these factors.

Vibration is just one cause of Raynaud's phenomenon. Other causes are connective tissue diseases, trauma, diseases of the blood vessels in the fingers, exposure to vinyl chloride, and the use of certain drugs. All the above causes reduce blood flow which produces white fingers in cold environments.

The number of affected people increases as the intensity and time of vibration exposure increases. The appearance of symptoms may occur months or years after the start of the exposure, depending on the intensity of exposure. This indicates a possible link between health effects and the total amount of vibration energy entering the hands. Two important features of the relationship between vibration exposure and health effects are:

- threshold value or tolerable vibration
- latent period

The threshold value of vibration is the maximum intensity of vibration to which workers can be exposed every workday for their entire full-time employment without developing VWF symptoms such as numbness, paleness or chill of fingers.

Table 3 - Factors that influence the effect of vibration on the hand

Physical Factors	Biodynamic Factors	Individual Factors
Acceleration of vibration.	Grip forces--how hard the worker grasps the vibrating equipment.	Operator's control of tool.
Frequency of vibration.	Surface area, location and mass of parts of the hand in contact with the source of vibration.	Machine work rate.
Duration of exposure each workday.	Hardness of the material being contacted by the hand-held tools, for example metal in chipping and grinding.	Skill and productivity.
Years of employment involving vibration exposure.	Position of the hand and arm relative to the body.	Individual susceptibility to vibration.
State of tool maintenance.	Texture of handle--soft and compliant versus rigid material.	Smoking and use of drugs.
Protective practices and equipment including gloves, boots, work-rest periods.	Medical history of injury to fingers and hands, particularly frostbite.	Exposure to other physical and chemical agents.
		Disease or prior injury to the fingers or hands.

The latent period for VWF is the time from the first occupational exposure to hand-arm vibration until the onset of symptoms. The latent period depends on the intensity of exposure. The higher the intensity, the shorter the latent period. The shorter the latent period, the more severe the resulting vibration syndrome is if exposure continues. Table 4 shows typical latent periods reported for workers in some occupations.

Vibration exposure definitely causes VWF. However, the acceptance of vibration syndrome as an industrial disease is hampered mainly because:

- Not every physician is trained to diagnose VWF.
- The causes of VWF cannot always be identified.
- There are no objective clinical tests to measure the impairment.
- The disease does not prevent workers from doing their jobs for a long time.
- The disease does not cause pain.

Table 4 - Average latent periods for vibration-induced diseases in different occupations

Occupation	Stage of VWF	Latency (years)
Foundry worker	Tingling	1.8
	Numbness	2.2
	Blanching	2.0
Shipyard worker	Tingling	9.1
	Numbness	12.0
	Blanching	16.8
Chain saw operator	Numbness	4.0
Grinder	Blanching	13.7

Source: Vibration effects on the hand and arm in industry. Edited by A.J. Brammer et al. New York: John Wiley and Sons, 1982.

5. HEALTH EFFECTS OF WHOLE-BODY VIBRATION

Whole-body vibration can cause fatigue, insomnia, headache and "shakiness" shortly after or during exposure. The symptoms are similar to those that many people experience after a long car or boat trip. After daily exposure over a number of years, whole-body vibration can affect the entire body and result in a number of health disorders. Studies of bus and truck drivers found that occupational exposure to whole-body vibration could have contributed to a number of circulatory, bowel, respiratory, muscular and back disorders. The combined effects of body posture, postural fatigue, dietary habits and whole-body vibration are the possible causes for these disorders.

Studies show that whole-body vibration can increase heart rate, oxygen uptake and respiratory rate, and can produce changes in blood and urine. East European researchers have noted that exposure to whole-body vibration can produce an overall ill feeling, which they call "vibration sickness."

Many studies have observed decreased performance in workers exposed to whole-body vibration. This effect seems to be related to the frequency of vibration.

Sea, air or land vehicles cause motion sickness when the vibration exposure occurs in the 0.1 to 0.6 Hz frequency range.

6. COMBINED EFFECT OF NOISE AND VIBRATION

Since most vibrating machines and tools produce noise, a vibration-exposed worker is likely to be exposed to noise at the same time.

Studies of hearing loss among lumberjacks revealed that for equal noise exposure, those with vibration-induced white finger (VWF) had greater hearing loss than those without VWF. The reason for this effect is not clear.

Studies of the effect of separate and simultaneous exposure to noise and whole-body vibration have concluded that whole-body vibration alone does not cause hearing loss. But simultaneous exposure to noise and vibration produces greater temporary hearing loss than noise alone.

7. MEASURING VIBRATION

Vibration is relatively difficult to measure. A complete exposure assessment requires the measurement of acceleration in well-defined directions, frequencies and times of exposure. The hand-grip force on a tool affects the amount of vibrational energy entering the hands and is another important factor in the assessment. To monitor each of these factors for each worker would clearly be impractical. Most jurisdictions and agencies use acceleration as a measure of vibration exposure for the following reasons:

- Several types of instruments are available for measuring acceleration.
- Measuring acceleration can also give information about velocity and amplitude.
- Some researchers feel that the degree of harm is related to the magnitude of acceleration.

A typical vibration measurement system includes a transducer to sense the vibration, tape recorder, frequency analyzer, and a display such as a meter, printer or recorder. The transducer, called an accelerometer, produces an electrical signal. The size of this signal is proportional to the acceleration applied to it. The frequency analyzer determines the distribution of acceleration in different frequency bands. Vibration meters equipped with accelerometers can be used for instantaneous vibration measurement. Some types of sound level meters are capable of measuring vibration. For more information on vibration measurement, consult the Further Reading list or contact CCOHS.

8. EXPOSURE GUIDELINES

Many Canadian occupational health and safety agencies have not issued regulations to limit vibration exposure. In the absence of formal regulations, these Canadian agencies often use guidelines developed by foreign and international agencies.

Hand-Arm Vibration

ACGIH

The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for hand-held tools. Table 5 lists acceleration levels and exposure durations to which, ACGIH has determined, most workers may be exposed repeatedly without severe damage to fingers or without progressing to stage 3 of the VWF. ACGIH advises that these guidelines be applied together with other protective elements, including vibration control.

Table 5 - The ACGIH threshold limit values for exposure of the hand to vibration in X, Y, or Z direction*

Total Daily Exposure Duration (hrs)	Maximum value of acceleration (m/s^2) in any direction*
between 4 and 8	4
between 2 and 4	6
between 1 and 2	8
less than 1	12

* Directions of axes in the three dimensional system

ISO 5349 Standard

The International Organization for Standardization has published a method for measuring vibration and interpreting the resulting data. This 1986 standard (ISO 5349) also gives the set of curves shown in Figure 2 that can determine exposure levels likely to cause the first signs of white finger in workers.

The horizontal axis in Figure 2 represents vibration acceleration. This is measured as RMS (Root Mean Square) weighted acceleration in m/s^2. RMS is a kind of average used for quantities that fluctuate with time about a central value. The measured value of acceleration at different frequencies is passed through a weighting filter that takes into account how humans respond to vibrations of different frequencies. The standard provides methods for calculating weighted RMS accelerations and equivalent acceleration values where the level of daily exposure varies with time.

Figure 2 can be used to assess the long-term effect of 4-hour per day exposures to hand-arm vibration. For example, the standard predicts that exposure to 50 m/s^2 vibration acceleration will cause 50 percent of exposed workers to reach stage 1 of Raynaud's phenomenon of occupational origin in about 1.2 years. At a vibration acceleration of 5 m/s^2, the standard predicts that it would take about 14 years for the same percentage of workers to reach stage 1. The data for which the curves were generated are limited, so they should not be used if exposure is greater than 50 m/s^2 or if the exposure duration exceeds 25 years.

Whole-Body Vibration

The standards and guidelines concerning whole-body vibration are designed to reduce vibration to a level where most workers can perform job tasks without discomfort.

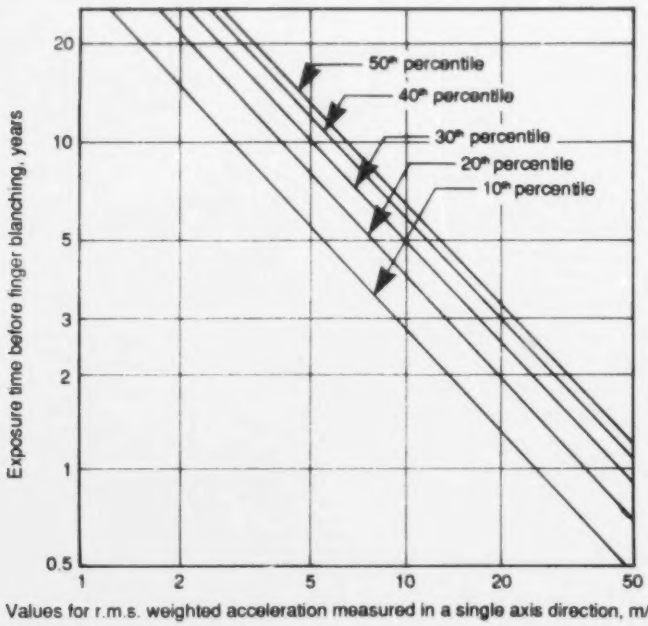

Figure 2 - Curves for exposure times of percentiles of population groups (ISO 5349.2) to suffer mild effects on tip of finger (see Stage 1, Table 2)

The most widely used document on this topic is ISO 2631--Guide for the Evaluation of Human Exposure to Whole Body Vibration. The American National Standards Institute (ANSI) and the Standards Secretariat, American Acoustical Society of America have issued the ISO 2631 standard as ANSI (33.18-1979) and ASA 38-1979, respectively. The ISO standard gives three different types of limits:

- the fatigue-decreased proficiency boundary
- an exposure limit
- a reduced-comfort boundary

The fatigue-decreased proficiency boundary is a limit for time-dependent effects that impair performance. For example, fatigue impairs performance in flying, driving and operating heavy vehicles.

The exposure limit is used to assess the maximum possible exposure allowed for whole-body vibration.

The reduced-comfort boundary is for the comfort of people travelling in airplanes, boats, and trains. Exceeding these exposure limits makes it difficult for passengers to eat, read or write when travelling.

Figure 3 gives the limits for 8-hour, 2-hour and 30-minute exposures. As with all standards, it is important to read and understand all the information before applying it in the workplace.

Example of use: If a person's vibration exposure is 0.5 m/S^2 at 0.25 Hz frequency, his daily exposure time should be 2 hours or less.

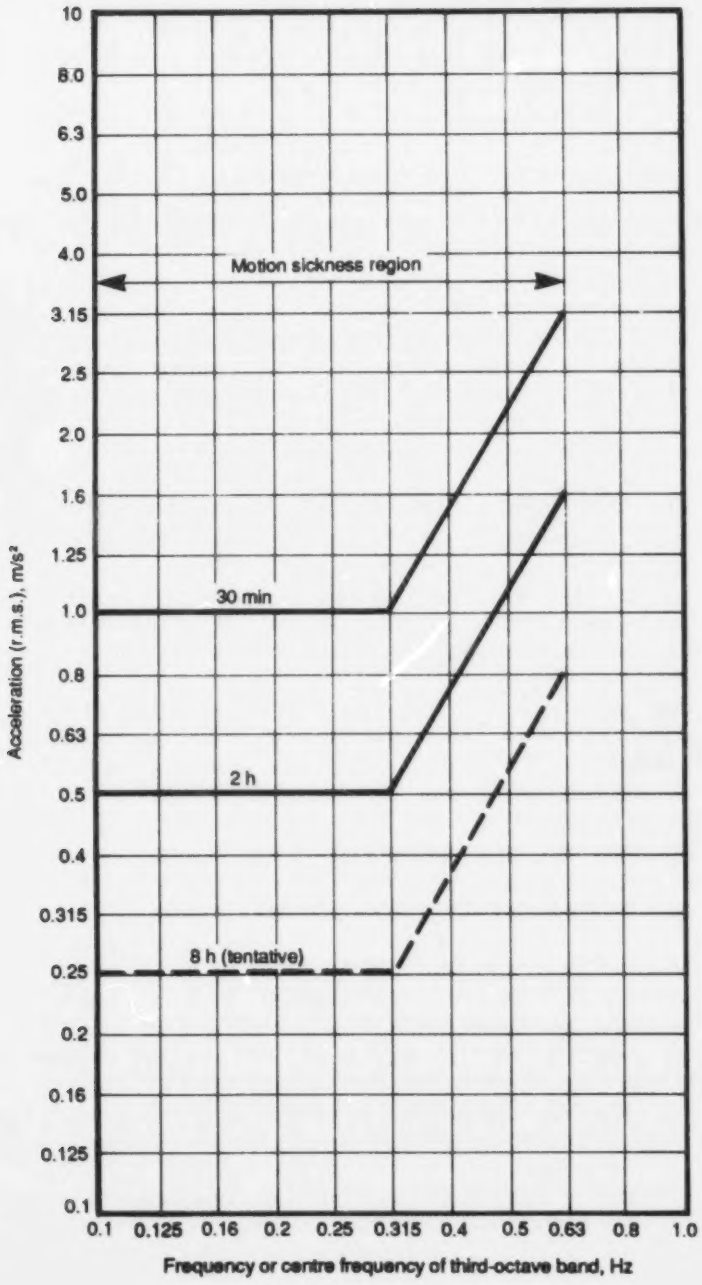

Figure 3 - ISO 2631 limits for whole-body vibration exposure

9. VIBRATION CONTROL

Protecting workers from the effects of vibration usually requires a combination of appropriate tool selection, good work practices, and education programs.

Hand-Arm Vibration

Anti-vibration Tools

Using anti-vibration chain saws reduces acceleration levels by a factor of about 10. These types of chain saws must be well maintained. Maintenance must include periodic replacement of shock absorbers.

A few pneumatic tool companies manufacture anti-vibration tools such as anti-vibration pneumatic chipping hammers, pavement breakers and vibration-damped pneumatic riveting guns. Because these anti-vibration designs are new, it is not clear how effective they will be in reducing the occurrence of VWF.

Anti-vibration Gloves

Anti-vibration gloves which use patented materials, can effectively absorb lower frequency vibration while retaining their overall shape.

Conventional gloves do not reduce low frequency vibration. But, since they provide some degree of warmth, conventional gloves may reduce the occurrence of vibration-induced white finger attacks.

Safe Work Practices

Along with using anti-vibration tools and gloves, workers should receive training and use the following advice:

- Employ a minimum hand grip consistent with safe operation of the tool or process.
- Wear sufficient clothing, including gloves, to keep warm.
- Avoid continuous exposure by taking rest periods.
- Rest the tool on the workpiece whenever practical.
- Refrain from using faulty tools.
- Maintain properly sharpened cutting tools.
- Consult a doctor at the first sign of vibration disease and inquire about the possibility of changing to a job with less exposure.

Worker Education

Training programs are an effective means of heightening the awareness of VWF in the workplace. They should include teaching workers how to properly use and maintain vibrating tools to avoid unnecessary exposure to vibration.

Whole-Body Vibration

Certain precautions help to minimize worker exposure to whole-body vibration. In addition to applying the ISO 2631 standard:

- Limit the time spent by workers on a vibrating surface.
- Mechanically isolate the vibrating source or surface to reduce exposure.
- Ensure that equipment is well maintained to avoid excessive vibration.
- Install vibration damping seats.

The vibration control design is an intricate engineering problem and must be implemented by qualified professionals. A number of factors specific to the individual work station govern the choice of the vibration isolation material and the machine mounting methods.

10. SUMMARY

Vibration exposure is possible in many occupations where a worker comes in contact with vibrating machinery or equipment. When a worker operates hand-held equipment such as a chain saw or jackhammer, vibration affects hands and arms and is called hand-arm vibration. When a worker sits or stands on a vibrating floor or seat, the exposure affects almost the entire body and is called whole-body vibration.

Hand-arm vibration causes white finger disease or Raynaud's phenomenon. Affected fingers turn white, especially when exposed to cold. Vibration-induced white finger disease is also accompanied by a loss of grip force and reduced touch sensitivity.

The effect of whole-body vibration is poorly understood. Studies of drivers of heavy vehicles have revealed a greater incidence of bowel, circulatory, musculoskeletal and neurological disorders.

Many Canadian workplaces do not have regulations concerning vibration exposure. But since vibration is known to cause ill health effects, reduce the level of exposure as much as practical. It is possible to do this by engineering controls, the use of protective equipment and safe work practices. The design of vibration damped equipment and engine mounting are the most effective engineering methods of controlling vibration exposure.

FURTHER READING

Baxter, J. Raynaud's phenomenon (white finger): a summary of the occupational health concern. Hamilton, Ontario: Canadian Centre for Occupational Health and Safety, 1989.

Gemne, G. et al. The Stockholm workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome (revision of the Taylor-Pelmear scale). Scandinavian Journal of Work, Environment and Health. Vol. 13, no. 4 (1987) p. 275-278.

Guide for the evaluation of human exposure to whole-body vibration. Geneva: International Organization for Standardization, 1978.

Guidelines for the measurement and assessment of human exposure to hand-transmitted vibration. Geneva: International Organization for Standardization, 1984.

Helmkamp, J.C. et al. Whole body vibration: a critical review. American Industrial Hygiene Association Journal. Vol. 45, no. 3 (1984) p. 162-167.

Pelnar, P.V. et al. A pilot study of the vibration induced disorders of the hands among forestry workers: final report. Montreal: McGill University, Institute of Occupational Health and Safety, 1980.

Pyykko, I. et al. Hand-arm vibration in the aetiology of hearing loss in lumberjacks. British Journal of Industrial Medicine. Vol. 38 (1981) p. 281-289.

Seidel, H. et al. Long-term effects of whole-body vibration: a critical survey of the literature. International Archives of Occupational and Environmental Health. Vol. 58 (1986) p. 1-26.

TLVs: threshold limit values and biological exposure indices for 1988-1989. Cincinnati: American Conference of Governmental Industrial Hygienists, 1988.

Vibration effects on the hand and arm in industry. Edited by A.J. Brammer et al. New York: John Wiley and Sons, 1982.

Vibration white finger in industry: a report, comprising edited versions of papers submitted to the Department of Health and Social Security in December 1973. Edited by W. Taylor et al. London: Academic Press, 1975.

Wasserman, D.E. Human aspects of occupational vibration. (Advances in human factors/ergonomics, 8). New York: Elsevier, 1987.

Wasserman, D.E. Raynaud's phenomenon as it relates to hand-tool vibration in the workplace. American Industrial Hygiene Association Journal. Vol. 46 , no. 12 (1985) p. B-10 - B-18.